

HICO Data User's Progress Report 2014 (Period: from october 2012 to april 2014)

Title of Proposal:

**“USE OF HICO DATA TO STUDY THE WATER QUALITY OF
COASTAL AND INLAND WATER BODIES”**

Principal Investigator: Jose Moreno

Address: University of Valencia
Depart. Earth Physics and Thermodynamics, Faculty of Physics
Scientific Park. Image Processing Laboratory (IPL)
C/ Catedrático José Beltrán, 2 46980 Paterna (Spain)

Phone (including country code): 0034963543112

FAX (including country code): 0034963543261

e-mail address: jose.moreno@uv.es

Co Investigators: Eduardo Vicente, University of Valencia, Department of Microbiology and Ecology, eduardo.vicente@uv.es;
Maria Rosa Miracle, University of Valencia. Department of Microbiology and Ecology. rosa.miracle@uv.es
Ramon Pena, University of Valencia, Image Processing Laboratory,
rpenamart@yahoo.es

Abstract

The current Project, as HICO data user, of the University of Valencia (Spain) was requested by 2012 January 18th and the first HICO acquisition on the approved target was in February 23rd 2012.

In this second period HICO has acquired 80 images over 4 targets (AlbuferaLake_SP, EbroBasin_SP, ESP_EbroBasinW, and the target of Barrax_Spain, with access to images permission). Was taken 72 images, but only good or acceptable to process 13, by different causes.

The Project investigators was involved, as since the start of the project, taking samples and optical information in the selected targets and, after the image reception, processing the data.

Additionally we continues trying to improve the integration in a new Tool to create an eventual L2 of processing with a new algorithm for atmospheric correction of HICO images,.

In that way several algorithms have been applied for estimation of some important limnological variables in order to obtain information and maps of the

main phytoplanktonic pigments and other physicochemical parameters, trying to incorporate the algorithms to the mentioned Tool.

In these lines we check different ways to fit the “in situ” data with the reflectance images in concordance with the very wide spectrum and the very good resolution conditions of the HICO bands.

Our team decided to apply an adaptation of the same approach of AC tools developed in the UV to rise an reflectance information more useful to apply the algorithms on bio-optical parameters.

In this moment we have a new Tool for Atmospheric Correction of HICO images from the first level (L1b) of process, testing with our images, and two of other HICO projects, to check his applicability. Now is in course the final version of that Tool, as a successful way to work with HICO.

A) Project summary

The goal of the present current project, submitted to HICO by the University of Valencia (UV) is to develop and validate algorithms what can be used by the user community to estimate water quality variables and parameters in coastal and inland waters, with HICO data.

In order to achieve this goal the project will be organised around the following main themes:

- Collection and compilation of inherent optical properties (IOP's) of lake water as well as other characteristics parameters on Spanish water bodies in the areas under investigation.
- Improvement of the atmospheric correction of HICO images over coastal and inland waters.
- Validation of the atmospheric correction and the retrieval of IOP and water constituents and the algorithms applied in the thematic mapping of limnological variables on the water bodies.

The proposal is initially focused in the lake Albufera de Valencia, eastern coast of Spain, including the very close coastal water and several inland water bodies, reservoirs, very abundant in this country (there are around 1500 reservoirs).

Some month after was incorporated two new target in the Ebro river basin to cover several inland water bodies in relation with the project on water quality in selected reservoirs of that demarcation.

This proposal try to provide basically algorithmic elements with more emphasis into the collection of IOP's for validation of the algorithms, to provide its general application to inland waters in Spain.

B. Status

Areas of work:

The UV project was requested, during this period, 3 targets as different zones of work on inland water bodies:

Target #1: AlbuferaLake_SP.

Valencia area in the Mediterranean coast, including several reservoirs of the Jucar Water Demarcation.

Center image Coordinates: Lat: 39.33° N; Lon: 0.36° W

Target #2: SP_EbroBasin.

Lleida area. Eastern Ebro river basin. Many reservoirs in several tributary basins in Huesca, Teruel and Lerida provinces.

Center image Coordinates: Lat: 41.856° N; Lon: 0.82° W

Target #3: ESP_EbroBasin.

Reinosa area. Western Ebro river basin. Ebro reservoir and several inland water bodies in the upper Ebro river basin.

Center image Coordinates: Lat: 42.5475° N; Lon: 3.2589° W

B.1. General Project Objectives

In the frame of a Project funded by the Spanish Water Management Authorities, the main objective is Monitoring, by hyperspectral remote sensing, the Water Quality, following the European Directives, through the Chlorophyll concentration evaluation in order to assess the trophic level, and, in many cases, the Phycocyanin concentration, alerting on Cyanobacteria presence, eventually toxic, in the water bodies.

In this second period of work with HICO images, acquired for this project since the 2012 February 23rd, the activity continues monitoring the water bodies, but was mainly focused in the line, open in the first period, to develop a new tool to Atmospheric Correction of HICO images, very important for rise the project objectives.

B.2. HICO Proposal Objectives

- Use the HICO imagery for Mapping of Chlorophyll-a and Phycocyanin (as Cyanobacteria indicator), its temporal and spatial distribution, testing several algorithms for Phytoplankton pigments evaluation.
- Validation and application of Algorithms for estimation of other limnological variables.
- Testing and improvement of atmospheric correction models in order to its adaptation to HICO bands, considering the adjacency effects and other anomalies, especially in the blue and red/NIR areas of the spectrum.

B.3. UV activities

B.3.1. Ground campaigns

After the Annual Meeting hold in Glasgow in October 2012, the field work plan has covered with operational constraints, the active dates selected, taking data in several sampling points and measuring the following parameters:

- Phytoplankton pigment composition using HPLC and other techniques.
- Phytoplankton taxonomic composition and bio-volume estimation.
- Nutrients concentration, physicochemical parameters analysis.
- Water optics: Above water radiometry. In water radiometry; Inherent optical properties measurement (absorption coefficients), etc.

In Albufera Lake, hypereutrophic water body, the phytoplankton population is usually dominated by Cyanobacteria for most of the period, with high biomass value, mainly represented by Chlorophyll-a (general phytoplankton) and Phycocyanin (specific of Cyanobacteria).

B.3.2. Imagery acquired

In the period september 2012 to april 2014 the HICO schedule commission was selected for this project 72 dates:

Date	GMT	Target	Orientation	Quality	Thematic maps
120911	1345	AlbuferaLake_SP	desc	OK	*
130321	0940	AlbuferaLake_SP	desc	OK	*
120311	1500	Barrax_Spain	desc	OK	Aux. for AC Tool
140306	1508	Barrax_Spain	desc	OK	Aux. for AC Tool
120907	1430	SP_EbroBasin	asc	OK	*
130315	1135	SP_EbroBasin	desc	OK	
140311	1235	ESP_EbroBasinW	desc	OK	*
121110	1345	AlbuferaLake_SP	desc	pC	*
130113	1230	AlbuferaLake_SP	desc	pC	*
130418	1540	AlbuferaLake_SP	asc	pC	*
120917	1030	SP_EbroBasin	desc	pC	
120920	0940	ESP_EbroBasinW	desc	pC	
131106	1425	ESP_EbroBasinW	desc	pC	

Table 1. Imagery used in the UV HICO Project

In summary:

- 72 selected for acquisition
- 13 used in the project [18.1 %] as showed in the table
- 59 discarded (cancelled, lock up, failed, cloudy) [81.9 %]

In many dates selected for HICO image acquisition we need to cancel the field work by cloudy conditions; in other dates the selection was cancelled

by other reasons (HICO operations, on board computer locked, etc.). The bad proportion of successful images suggest the convenience of consider the possibility of add any forecast system to can cancel, if necessary, the target to be imaged, before the time of acquisition, and with time to select a new target, in reserve, without weather problem.

B.3.2. Imagery acquired

In the period september 2012 to april 2014 the University of Valencia / HICO project was prepared several works showing the advances in the recalibration and atmospheric correction of HICO images and its integration in a Tool to process the data.

Some of that paper are:

C. Tenjo, A. Ruiz-Verdú, J. Delegido, R. Peña, N. Sabater, J. Vicent, and J. Moreno, “Desarrollo de un modelo semi-analítico para la estimación de clorofila en aguas continentales y su aplicación en imágenes HICO,” in **XV Congreso de la Asociación Española de Teledetección. AET, 2013**, pp. 309–312.

N. Sabater, J. Vicent, R. Peña, C. Tenjo, L. Alonso, L. González, J. Soria and J. Moreno, “Radiometric recalibration and atmospheric correction of hyperspectral HICO/ISS images for coastal and inland waters” in April 8-10, 2013: **8th SIG Imaging Spectroscopy Workshop, Nantes, France**.

J. Vicent, N. Sabater, C. Tenjo, A. Ruiz-Verdú, J. Delegido, R. Peña-Martínez and J. Moreno, “HICO level-2 data processing toolbox for the atmospheric correction and the retrieval of water quality parameters”. Paper presented for the **6th Workshop on Hyperspectral Image and Signal Processing: Evolution in Remote Sensing, Lausanne, 24 – 27 june 2014**.

C. Advances in the achievements

C1. Development of a toolbox for the atmospheric correction and the retrieval of water quality parameters from HICO images.

C.1.1. Ways to improve the quality of reflectance values.

Hyperspectral remote sensing is an important tool for monitoring water quality as it provides valuable information about water components (chlorophyll, suspended solids, etc.).

A project to evaluate the water quality of coastal and inland waters was submitted to Hyperspectral Imager for the Coastal Ocean (HICO) by University of Valencia and funded by the Spanish Water Management Authorities. The main objective is to develop and validate algorithms for the water quality monitoring, specifically Cyanobacteria dynamics, by remote sensing using HICO data. This project is organized in three main tasks:

- In-situ acquisition of water quality parameters for inland water bodies.
- Processing of HICO images up to a second processing level (Level-2 [L2]), including radiometric sensor recalibration, atmospheric correction and determination of Chlorophyll-a, Phycocyanin, etc.
- Validation of the implemented L2 algorithms and the retrieval of water quality parameters.

The HICO sensor acquires Top-Of-Atmosphere (TOA) radiance in 128 spectral bands ranging from 350nm to 1080nm at 5-7nm spectral resolution and 90m of Ground Sampling Distance. Nevertheless, spectral bands outside the 400 - 900nm range are not available due to the low sensitivity of the sensor at these wavelengths.

This Annual report describes the Algorithms and tools developed to process HICO data up to an L2 level with water quality products and show some preliminary results of atmospheric correction and retrieval of limnological parameters.

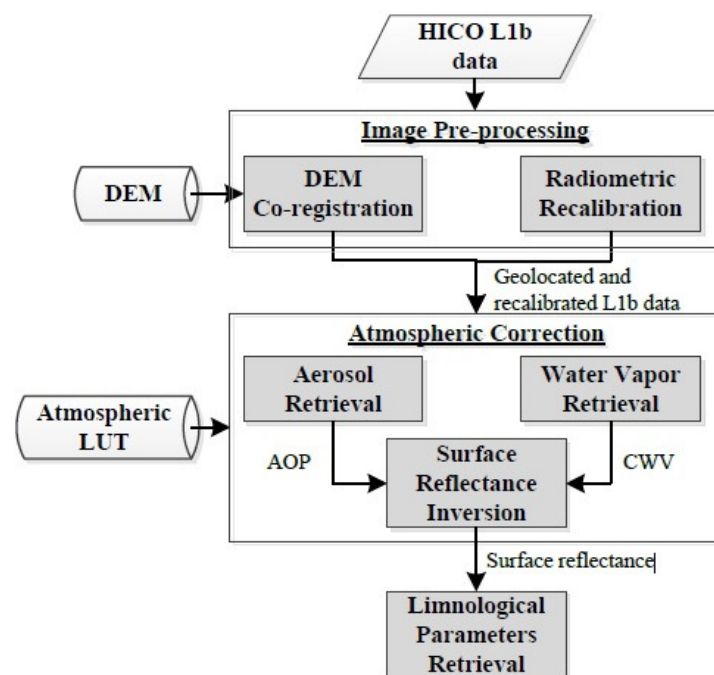


Fig. 1. HICO toolbox software architecture.

C.1.2. Description of the HICO Toolbox software.

The architecture of the developed HICO L2 image processing chain is schematized in Fig. 1. It consists of three high level modules:

- 1) The image pre-processing module;
- 2) the atmospheric correction module; and
- 3) the limnologic parameters retrieval module.

Each of these three modules is decomposed in lower-level modules (grey boxes in Fig. 1) that are sequentially executed producing data used by the subsequent modules. A brief description of the theoretical aspects of the algorithms implemented in each module is given in the following sections.

C. 2. Image processing

C. 2. 1. Image pre-processing

The first step on the HICO toolbox consists into a radiometric recalibration of the Level-1b (L1b) TOA radiance data to reduce the impact of sensor mis-calibration and stray-light reported in [2, 3]. In addition, the radiometric recalibration is needed to keep the consistency with the atmospheric model inversion.

A vicarious calibration field campaign in the Albufera Lake (Valencia, Spain) was carried-out on the 21/03/2013 at the same time of the sensor overpass (09h:40:45 UTC). Nearly 1300 radiometric measurements were acquired over a rice field of 1.6km² with an ASD FSFP spectroradiometer. Aerosol and water vapor data from AERONET Burjassot site (Valencia) was taken to fix the atmospheric conditions. The ground measurements were propagated through the atmosphere using MODTRAN5 Radiative Transfer Model (RTM) to simulate the HICO acquired signal. Fig. 2 shows the simulated (L_{sim}) vs. acquired at-sensor (L_{sen}) TOA radiances used to recalibrate the sensor so that $L_{sim} = L_{sen}$.

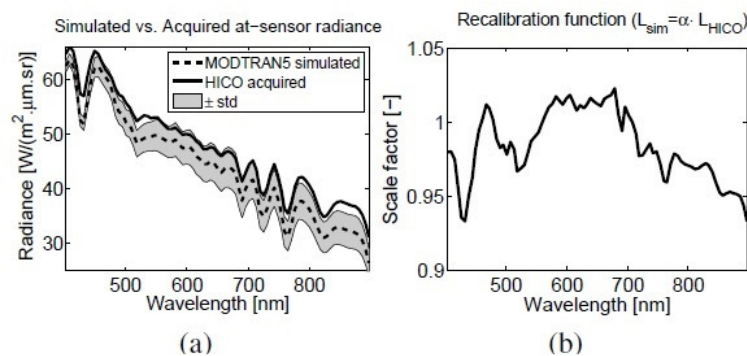


Fig. 2. (a) Acquired vs. simulated TOA radiance; (b) HICO radiometric recalibration factor.

Aside the radiometric recalibration, the L1b data is coregistered with a Digital Elevation Model (DEM) in order to consider the surface topography to correct for the illumination conditions and surface height.

3.2.2.1. Atmospheric correction

For near-nadir pointing sensors such as HICO, a Lambertian surface reflectance can be considered, which allows approximating the at sensor radiance by the following well-known equation:

$$L_{sen} = L_0 + \frac{1}{\pi} \frac{(E_{dir}\mu_{il} + E_{dif})T^{\uparrow}\rho}{1 - S\rho} \quad (1)$$

where L_0 is the atmospheric path radiance; E_{dir} , E_{dif} is the at-ground direct/diffuse irradiance; μ_{il} is the cosine of the illumination angle accounting for the surface roughness; ρ is the surface reflectance; T^{\uparrow} is the total upwards atmospheric transmittance; and S the atmospheric spherical albedo that accounts for multiple scattering between the surface and atmosphere.

3.2.2.1. Retrieval or aerosol optical properties

Most image-based AOP retrieval algorithms assume a given set of aerosol types in the model inversion and thus fixing the wavelength dependency of the Aerosol Optical Depth (AOD), the multiple scattering coefficient and the phase function.

The AOP algorithm does not make assumption on the aerosol type, but the following approximations on the aerosol AOPs are considered:

- 1) the spectral variation of the AOD is defined by the Angström law given the AOD at 550nm, τ_0 , and the Angström exponent, α ;
- 2) the Henyey-Greenstein phase function (parameterized by G) models the angular dispersion. The retrieval of τ_0 , α and G consists on a MODTRAN5 atmospheric Look-Up Table (LUT) inversion based on the spectral mixing method in [4] that minimizes the cost-function in (2):

$$\delta^2 = \sum_{\lambda}^N \sum_i^P \omega_{\lambda} (L_{\lambda,i}^{sim} - L_{\lambda,i}^{sen})^2 \quad (2)$$

where P simulated pixel radiances assume a spectral mixing of two artificial end-members (vegetation and bare soil) for the surface reflectance, i.e. $\rho_i = C_{v,i}\rho_v + C_{s,i}\rho_s$.

A weighting spectral-dependent function, ω_{λ} , forces the minimization of the cost-function for a better fit at lower wavelengths, where the effect of aerosols is higher.

3.2.2.2. Retrieval of columnar water vapor

A differential absorption technique calculates the ratio between channels inside and outside the water vapor absorption band (measurement and reference channels respectively). The Linear Regression Ratio (LIRR) [5] has been implemented in the HICO toolbox, calculated by averaging the two bands at the bottom of the absorption band ($\lambda_m \approx 820\text{nm}$); the reference channel is obtained by the linear regression (LIR) of the channels next to the absorption band:

$$R_{LIRR} = \frac{\bar{L}_m}{LIR([\lambda_m], [\lambda_r])|_{\lambda_m}} \quad (3)$$

The CWV is retrieved by an atmospheric LUT inversion minimizing the cost-function $\chi = R_{LIRR}^{sim} - R_{LIRR}^{sen}$ between the sensed and simulated LIRR ratios, pixel-wise due to the parameter high spatial variability.

3.2.3. Incorporation of water chlorophyll concentration

There are many indexes developed for assess limnological variables using remote sensing. Other method (AUNAC) for Chlorophyll-a (Chla) estimation [6] is based on the integral of the reflectance spectrum in a region in which its variation is due to the scattering of suspended solids. The normalization of the integral allows to separate the index variations from the mineral particles and makes it dependent only on phytoplankton.

The AUNAC index has been included in the HICO toolbox, calibrated (see Fig. 3) with a dataset of reflectance and Chl-a concentration values in the Albufera Lake acquired by the CEDEX (Ministry of Public Works of Spain, 2002 -2007).

4. VALIDATION OF CONCEPT

4.1. Description of image targets and field data

A set of HICO images (see Tab. 1) acquired over the Albufera Lake and the Barrax site (La Mancha, Spain) have been processed with the HICO L2 toolbox. The Barrax site is a large and flat agricultural area at around 700 masl altitude, generally clear atmospheric conditions and important contrast of vegetated crop fields and dry bare soils; has been used in past field campaigns such as ESA's SPARC and SEN2FLEX for calibration of space borne instruments and validation of image processing algorithms.

The Albufera Lake is a hypertrophic freshwater coastal lagoon, with chlorophyll-a concentrations ranging from $30\mu\text{g/l}$ to more than $300\mu\text{g/l}$.

ID	Target	Date	Time	In-situ data
#1	Albufera Lake	23/02/2012	14:59:44	Chl-a
#2	Albufera Lake	26/02/2012	13:44:56	Chl-a
#3	Albufera Lake	23/03/2012	10:00:35	Chl-a
#4	Albufera Lake	21/03/2013	09:40:45	Reflectance
#5	Barrax	11/03/2012	14:59:45	Reflectance

Table 1. Processed HICO images

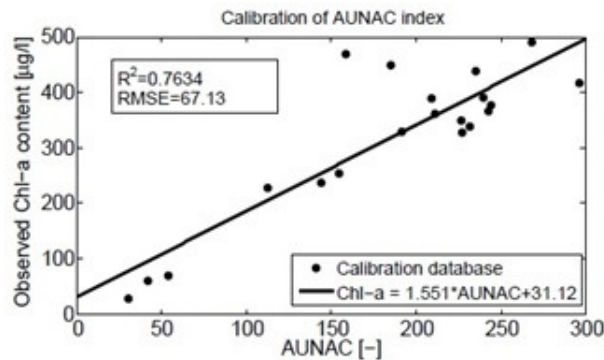


Fig. 3. Calibration of AUNAC index by linear regression with Chl-a in-situ measurements.

Radiometric measurements were taken with an ASD FSFP and ASD FieldSpec 3 spectroradiometer. A total of 15 in-situ Chl-a water concentration measurements were acquired by the Ecology Department of the University of Valencia at the same date/time of the sensor overpass (images #1 - #3) acquired with a Phytoflash active fluorometer TURNER 2500-000.

4.2. Surface reflectance and in-land water products

The radiometric ground reflectance measurements (Albufera) are compared (Fig. 4) with the surface reflectance values, with a good fit between the retrieved and reference data. For the Barrax site, the results are less accurate by the different date and time of acquisition of the ground measurements and the HICO image.

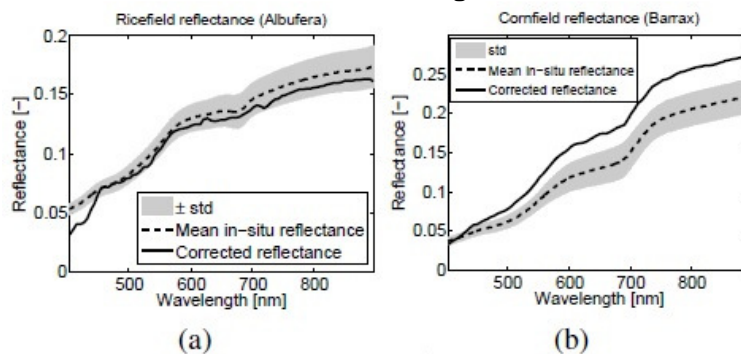


Fig. 4. Atmospherically corrected reflectance vs ground data: (a) Albufera bare rice field; and (b) bare corn field in Barrax.

The retrieved [Chl-a] in the Albufera lake show a good linear correlation with respect the in-situ measurements (Fig. 5).

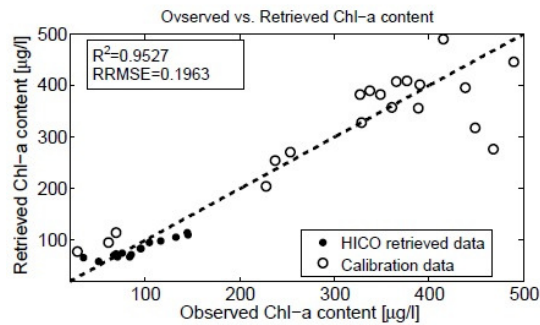


Fig. 5. Validation of retrieved Chl-a concentration.

The AUNAC index applied to Albufera (2012/03/23) showed in Fig. 6. The algorithms for estimation of Chlorophyll-a and Phycocyanin [9] was applied too to the useful HICO images acquired for the UV targets. The resulting thematic maps are included in the final Annex.

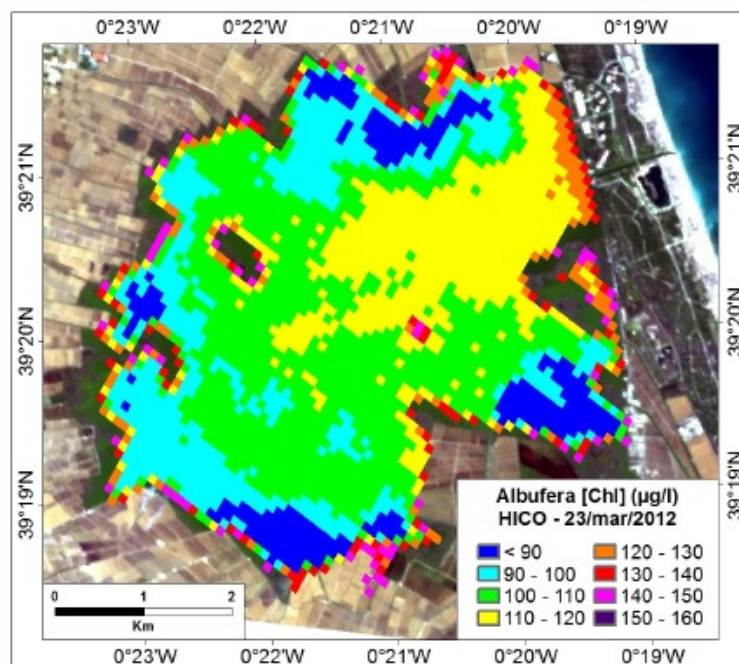


Fig. 6. Retrieval of Chl-a concentration in Albufera lake.

5. PERSPECTIVES

The toolbox includes the image processing algorithms to recalibrate the HICO L1b data; refine the image geolocation by coregistration with a DEM; atmospherically correct the L1b data (aerosol and water vapor retrieval) for the inversion of surface reflectance, and retrieve concentration [Chl-a] in water bodies.

The toolbox has been applied over a set of HICO images with ground radiometric and limnology data was available, with good agreement between the in-situ data and the retrieved data.

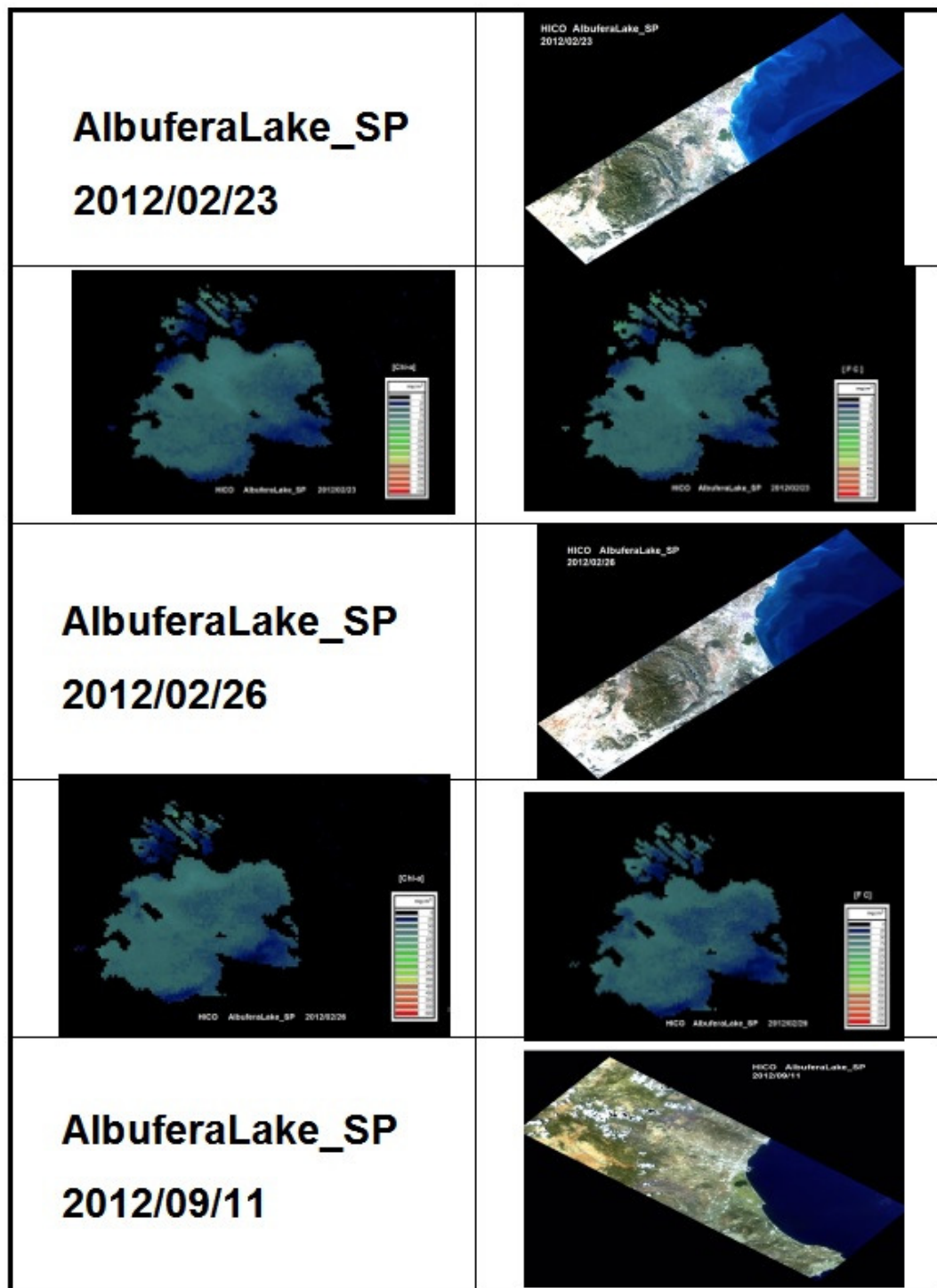
Future work will improve the quality of the atmospheric correction and co-registration with the DEM. In addition, a number of water quality algorithms available in the literature will be implemented in the toolbox, and will include too the acquisition of additional limnology and radiometric measurements database to rise a more robust validation of the full processing chain.

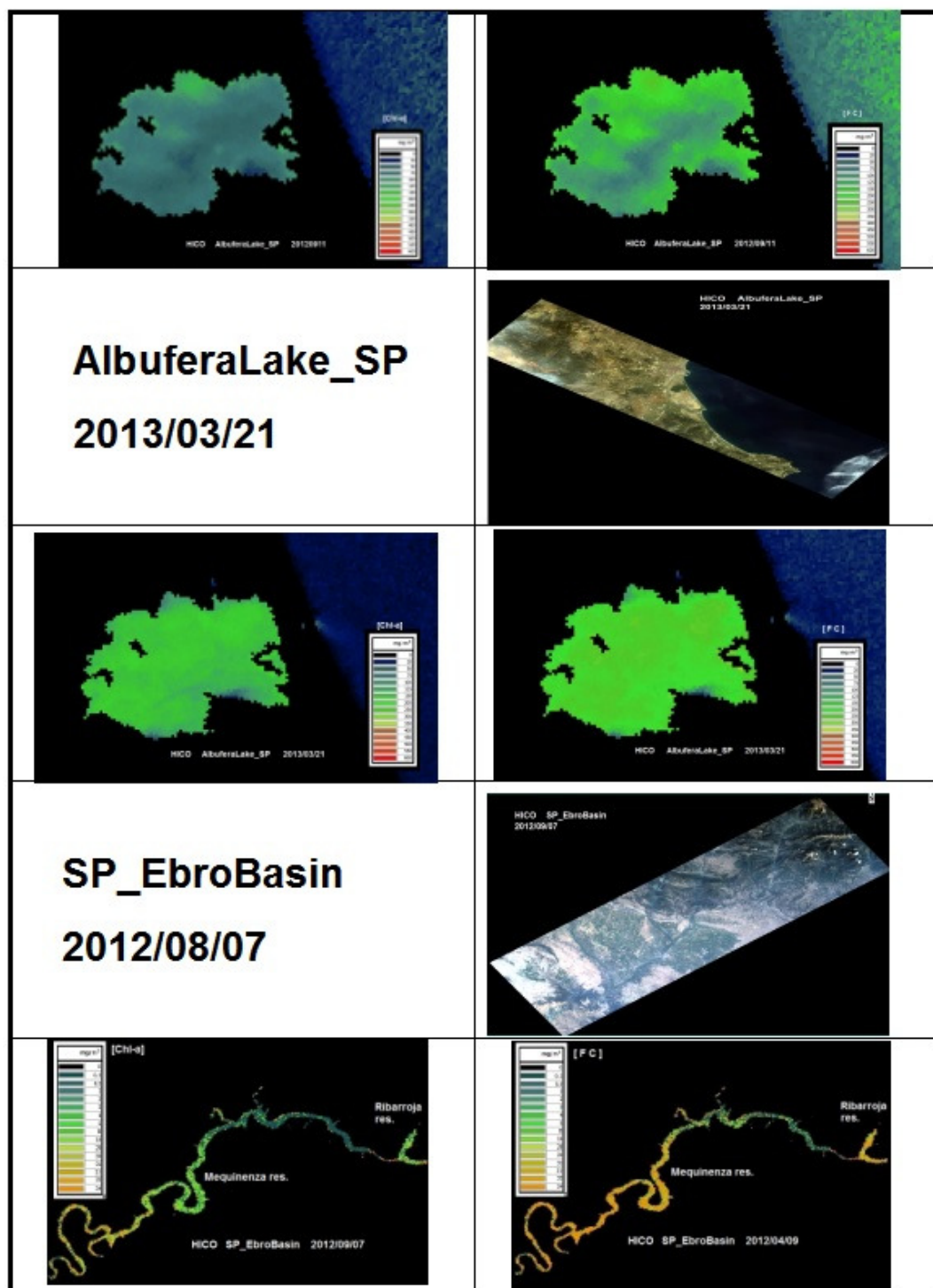
In the next period of Project activity the University of Valencia will continues the acquisition of in situ data to support the HICO imagery acquisitions.

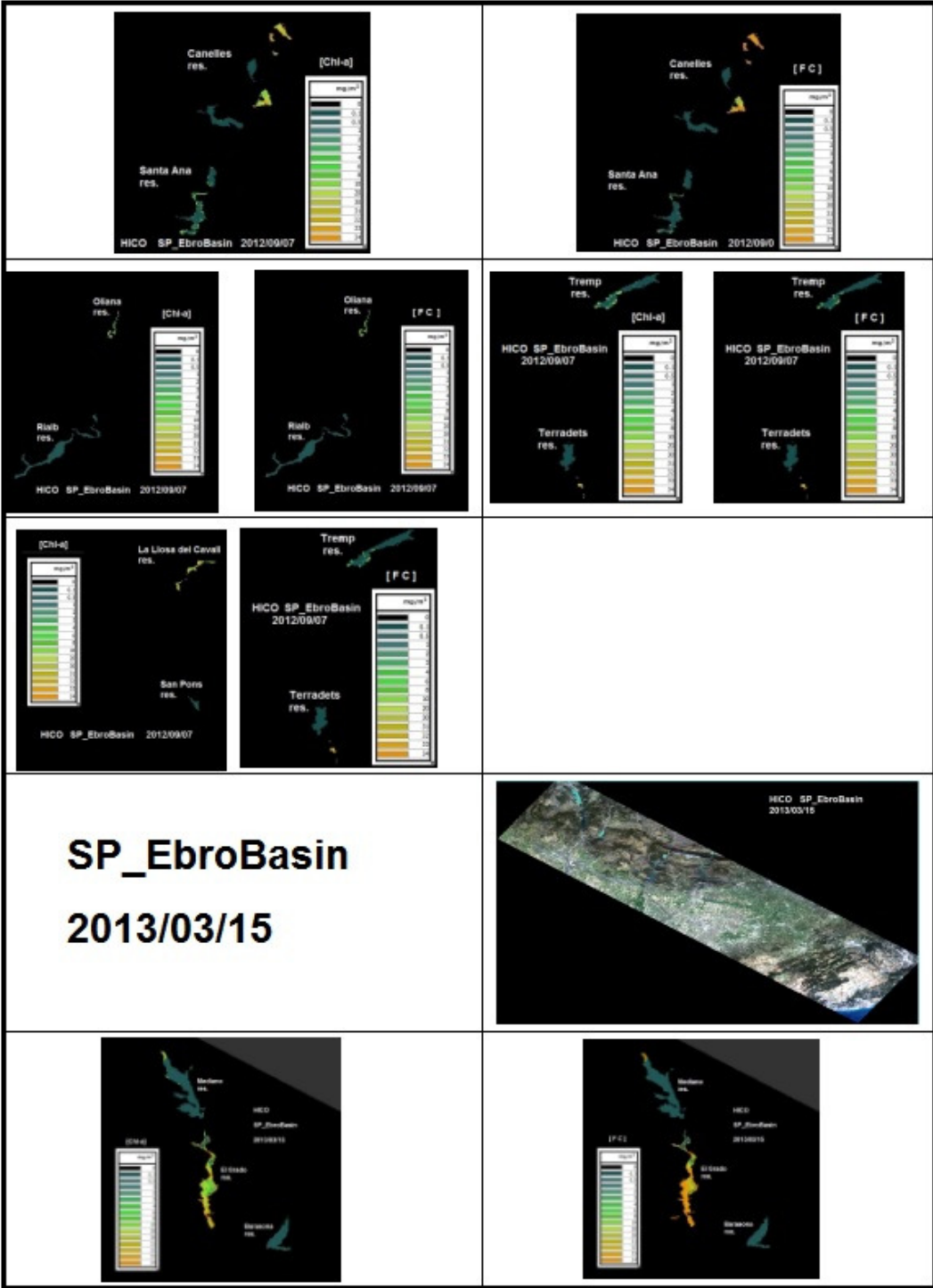
5. REFERENCES

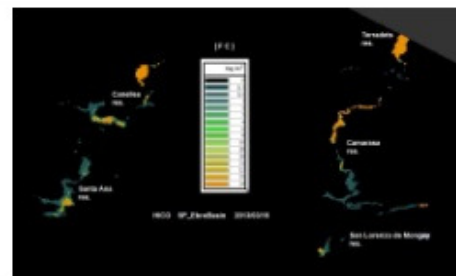
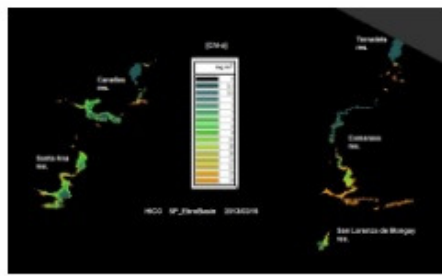
- [1] R.L. Lucke, M. Corson, N.R. McGlothlin, S.D. Butcher, D.L. Wood, D.R. Korwan, R.R. Li, W.A. Snyder, C.O. Davis, and D.T. Chen, "Hyperspectral imager for the coastal ocean: Instrument description and first images," *Applied Optics*, vol. 50, no. 11, pp. 1501–1516, 2011.
- [2] R.-R. Li, R. Lucke, D. Korwan, and B.-C. Gao, "A technique for removing second-order light effects from hyperspectral imaging data," *IEEE Trans. Geosci. Remote Sens.*, 2011.
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- [9] L. Guanter, A. Ruiz-Verdú, D. Odermatt, C. Giardino, S. Simis, V. Estellés, T. Heege, J-A. Dominguez-Gomez, J. Moreno, "Atmospherical correction of ENVISAT/MERIS data over inland waters: Validation for European Lakes" *Remote Sens. Environ.*, vol. 114, no. 3, pp. 467–480, 2010.

ANNEX THEMATIC MAPS

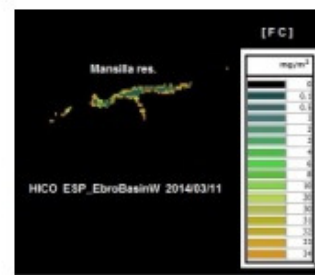
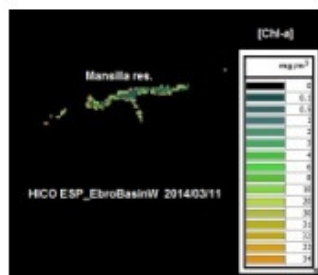
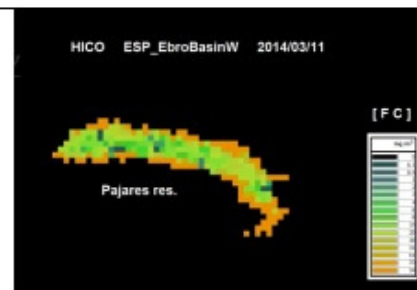
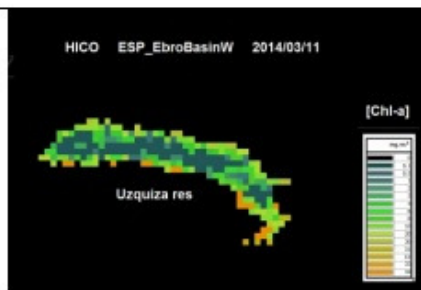
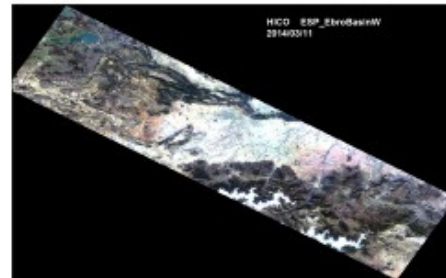


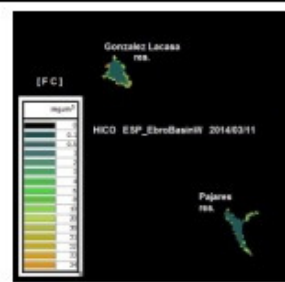
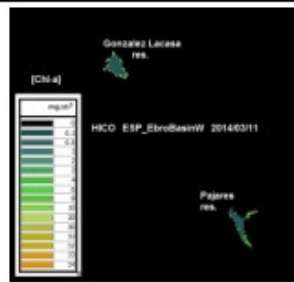




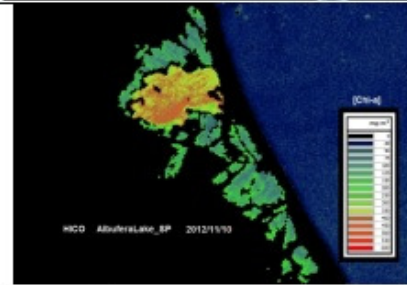
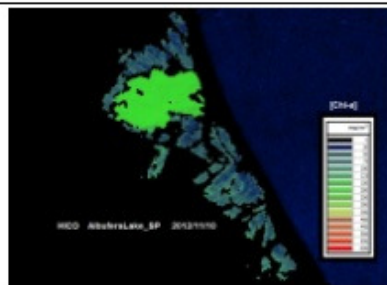
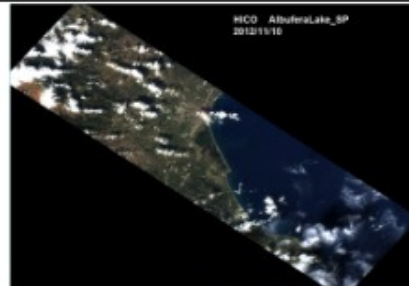


ESP_EbroBasinW 2014/03/11

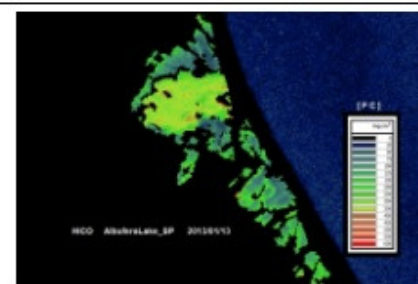
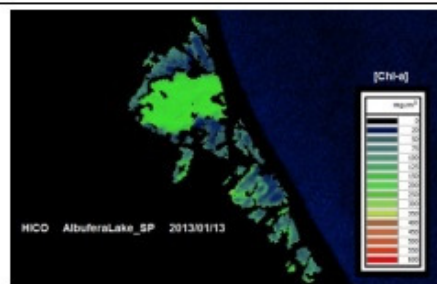
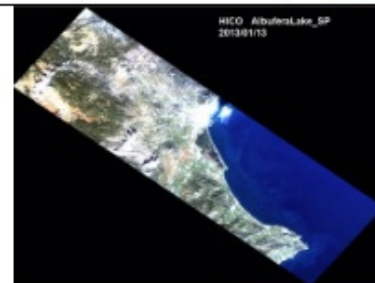




AlbuferaLake_SP
2012/11/10



AlbuferaLake_SP
2013/01/13



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